



MTS MUV

2017-2018

Manned Underwater Vehicles 2017-2018 Global Industry Overview

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ABSTRACT

The Manned Underwater Vehicle industry continues to build momentum into 2018, much of this has been driven by strong market trends and technology. There is renewed growth in the luxury yachting industry, in citizen science and in ocean philanthropy. Tourism submersibles offers high-end touring expeditions for boutique destinations and specialty cruise ships. In Asia, notably China, Japan and India, deep ocean science is gathering attention for research and commercial applications. The industry also benefits from an accepted use of lithium batteries by class societies and strong developments in the areas of navigation and communication technology. Finally, while military development typically focuses on unmanned capabilities, there is more investment in deep submergence submarine rescue vessels.

The industry maintains an impeccable safety record, with zero recorded fatal incidents in over 40 years. A total of 122+ vehicles operate privately and commercially in tourism, research or expedition work. Most of these submersibles are designed to international safety standards and classed by one of more than a dozen Class societies that are part of IACS (International Assoc. of Classing Societies.) This dedication to safety and accepted design rules is reflected in the fact that 92% of all operating submersibles were designed, fabricated and tested under third party classification society review.

The MTS MUV database tracks a total of 320 submersibles of which over 160 are active around the world. This paper reviews the general classification system of MUV's with special consideration of regulations and vessels working at 300m, 1000m and the challenging hadal zone that reaches to depths of 7000m and beyond. This discussion touches on the distribution of MUVs for different market applications, international class societies, non-submersibles that make the news as MUVs used in the narcotics industry and military vehicles used for submarine rescue capabilities. The last section highlights the accomplishments and challenges of active manned submersibles deployed around the world in 2017- 2018.

GENERAL REVIEW

The Manned Underwater Vehicle industry continues to build momentum into 2018. The industry has been propelled by strong market trends, and continues to be supported by the industry’s regulatory framework, safety record, and professionalism. There is renewed growth in the luxury yachting industry, and citizen science and ocean philanthropy has been buoyed by robust stock market performances. In Asia, notably China, Japan and India, deep ocean science is gathering more attention for research and commercial applications. Tourism submersibles continue to offer high-end touring expeditions for boutique destinations and specialty cruise ships. Finally, while military development typically focuses on unmanned capabilities, there has been investment in deep submergence submarine rescue vessels.

The Marine Technology Society’s Manned Underwater Vehicles (MTS MUV) Committee provides a forum for all in the industry who design, manufacture and operate human occupied vessels for extreme ocean environments. Competitive innovation, engineering advancements and leadership contribute to the long-term business growth essential to any ocean exploration initiatives. The MUV industry is comprised of 85 international member companies; including 50 MUV manufacturers of which 38 are commercial companies and 12 state agencies. MTS MUV divides the industry into four major categories: Research, Tourism, Government/military and Commercial/personal and distinguishes three groups by depth range of operation. The depth range groups include vehicles that operate deeper than 1000m (Group 1); MUVs that operate from 300-1000m depth capability (Group 2); and those that operate in the range of less than 300m range (Group 3). Table 1 shows the general distribution of MUV applications:

<i>Application</i>	<i>No. Vehicles</i>	<i>%</i>
Research	14	8.75
Tourism	36	22.5
Military/Gov’t	46	28.75
Commercial/Personal	64	40.0
TOTAL	160	

Table 1 – MTS MUV in operation in 2017 by sector of operation

MTS MUV Database: The MTS MUV committee maintains a database that tracks a total of 320 submersibles of which over 160 are active around the world, providing a capacity of 1624 seats. This includes 38 military deep submergence vehicles used for submarine rescue/support operations. A total of 122+ vehicles operate privately and commercially in tourism, research or expedition work. This data does not include historical submersibles that have been inactive for

more than 25 years or any personal/home-built (P/HB) submersibles because this population is too difficult to track. The best P/HB estimate in the United States would be 40 to 60 active vehicles, and possibly an inventory of two to three times this amount as a total roster. These vehicles are designed and built by industry craftsmen with aptitude but who do not use formal design and testing documentation. It is difficult to assess the scope of such vehicles in Europe, Asia and elsewhere, but private developments abound.

MUV Certification and Classification

The MUV industry maintains an impeccable safety record, with zero recorded fatal incidents in over 40 years. This dedication to safety and accepted design rules is reflected in the fact that 92% of all operating submersibles were designed, fabricated and tested under third party classification society review. Only 8% of operating vehicles are unclassified, and not formally documented or reviewed by a third-party agency.

The majority of submersibles in the MTS MUV database are designed to international safety standards and classed by one of the many Class societies that are part of IACS (International Assoc. of Classing Societies). The main Class societies for MUV rules include ABS, DNVGL and LR. A list of the MUVs operating per each Class society are in Table 2. The table shows the number subs operating “In Class”, those operating “out of class”, meaning they were designed to class but dropped out of the class survey schedule, and “un-classed” subs, including designs that were not formally documented for third party review.

ABS	American Bureau Shipping	USA	33	21%
BCS	Bulgaria Class Society	Bulgaria	1	1%
BV	Bureau Veritas	France	5	3%
CCS	China Classification Society	China	4	3%
CN	China Navy	China	4	3%
DNVGL	DNVGL	Norway/DE	21	13%
IRS	Indian Register of Shipping	India	1	1%
KR	Korean Register of Shipping	Korea	0	0%
LR	Lloyd's Register	UK	49	31%
NAVSEA	US Navy	USA	3	2%
NK	Nippon Kaiji Kyokai	Japan	4	3%
RINA	Registro Italiano Navale	Italy	3	2%
RS	Russian Maritime Register of Shipping	Russia	4	3%
None	Un-classed		12	8%
OUT	Out of Class Status		16	10%

160

Table 2 – 2017 MUV Industry Certification and Classification Status by IACS societies

MUV Industry Regulations

The Manned Underwater Vehicles (MUV) industry has evolved and grown in the past 25 years. Today it encompasses a wide range of vehicle types: Personal-amateur built MUVs, third party built experimental vehicles, professional classed (IACS) submersibles, large commercial tourism subs, military vehicles and commercial submarines. The industry is guided by an impressive set of internationally recognized safety design standards and rules: ABS, DNVGL, LR, ASME PVHO, USCG NVIC, CISR and more. These rules focus primarily on the vehicle “Design”. There are very few guidelines that focus on the MUV Operations aspect.

This has not been a significant issue in the past but with a growing and evolving market, current operations guidelines have become cumbersome, creating repeated and unproductive legal disputes over interpretations. Our long-term objective is to create a positive environment for MUV innovation, technology development, and commercial growth within the industry while guaranteeing public safety. The MUV Industry is currently engaged in constructive discussions to shape its future. Entrepreneurship is at the heart of all innovation, yet it is a constant challenge to balance innovation and public safety; to figure how the public, media and regulatory agencies can readily identify between different categories of submersible operations.

No	Current US Coast Guard Designation	MUV Proposed REVISED CATEGORY	APPLICABILITY
1	SUB-Chapter T Small Passenger Vessels	Passenger Tourist Submersibles	Submersibles built for commercial tourism - IACS CLASSED - Flag State (COI) Certificate of Inspection
2	SUB-Chapter C Uninspected Vessels	Commercial Submersibles	Commercial & Research submersibles - IACS CLASSED - Flag State COI not required for MUVs of six (6) Persons or less
3	SUB-Chapter C Uninspected Vessels	Uninspected Submersibles	Private & Commercially built Submersibles - UNCLASSED - Experimental Operation
4	Recreational Submersibles	Personal Submersibles	Home built, self-operated personal subs - UNCLASSED - Personal non-commercial Operation only
5	Submarines	Submarines	Classed Submarines / Work / Passengers - IACS CLASSED - Flag State (COI) Certificate of Inspection

Table 3 – Proposed MUV Operations Consensus Standard Category Framework

MUV operation regulations in the US have not been reviewed since 1993 and the MUV industry is formulating an updated, simpler regulatory framework that can be adopted globally and will

classify the many types of “Operations” according to the type of work/application performed and level of formal documentation presented to the Port Authorities. Proposed outlines were discussed during the 2018 MUV Symposium at Underwater Intervention and the MTS MUV committee continues to gather inputs from industry members through 2018. Five Categories have been proposed, based on the level of formal review of the design documentation. This includes a category for Tourist Submersibles requiring formal Classification of the design as well as Flag State certification; Commercial Submersibles which include Classed design and preclude Flag State certification if they involve six (6) or less participants; Experimental, un-classed submersibles which are developed commercially but where there is no formal third party design documentation review; and a Personal submersible category, where the design documentation is held by an individual. Finally, the framework includes a separate category for Submarines, fully autonomous vessels that can go out on multi-day expeditions without a surface support vessel. These include very few instances today but need a separate category looking ahead. Table 3 shows a general outline of the Framework in consideration.

Summary Review of Submersibles by Depth Classification

The MUV technologies, although similar across all types of vehicles, distinguishes three groups by depth range of operation. These general groups divide the MUVs into vehicles that operate deeper than 1000m (Group 1), also a benchmark commercial delimiter since vehicles with deeper capabilities are subject to US export restrictions; MUVs that operate from 300-1000m depth capability (Group 2); and more versatile types of MUVs that operate in the range of less than 300m range (Group 3).

GROUP 1 (> 1000m) Hadal Depth MUVs

This group of MUVs does not receive many newcomers, but the last two additions have been from China. In 2012, China launched the JIAOLONG. This vessel is owned by COMRA (China Ocean Mineral Resources R&D Association) and is operated by the China State Oceanic Administration (SOA) run National Deep Sea Center. JIAOLONG is the deepest research vehicle at 7000m rating. Its popularity in China created a surge of scientific interest for deep ocean research, and a backlog of dive requests because it is a single vehicle capacity. In response, China worked on the Deepsea Warrior, a new 45000m rated research submersible, specifically designed for its national science community, released in 2017. It was built as a lighter, nimbler vehicle with an effort to maximize national content in the design and construction. It is rated to 4500 meters, an equivalent to the current state of the American ALVIN. The China Ship Scientific Research Center (CSSRC), which designed and built both deep subs, reported a 95% “made in China” content in the new submersible.

France, Japan and USA maintain their existing deep submergence vehicles. Woods Hole Oceanographic Institution (WHOI) announced that ALVIN is scheduled to complete its Phase 2 overhaul to its full depth capacity of 6500m by 2020. Two other deep submersibles were added to the database for Russia, although the subs are not new. These are RUS and CONSUL, which have been appearing notably in public articles. These AS37 type are Russian versions of the MIR submersibles. The two MIRs are still at the PP Shirshov Institute in Moscow but are laid up and not operational. The two AS37 vehicles are primarily operated by the Russian Navy. Since the twin MIR submersibles are within reasonable range (technically and economically) to be put back in operation, Russia holds a unique deep ocean MUV force.

Country	Name	Depth (m)	No. Pax	Operator	Year Built	CLASS	Manufacturer
China	JIAOLONG	7000	3	China NDSC/ COMRA	2009	CCS	China Ship Scientific Research Center
Japan	SHINKAI 6500	6500	3	JAMSTEC	1989	NK	Mitsubishi Heavy Industry
France	NAUTILE	6000	3	IFREMER	1985	BV	IFREMER
Russia	RUS AS-37	6000	3	Russian Navy	2001	Russia Navy	Malakhit Design Bureau / Admiralty Yard
Russia	CONSUL AS-37	6000	3	Russian Navy	2009	Russia Navy	Malakhit Design Bureau / Admiralty Yard
Russia	MIR 1 *	6000	3	PP Shirshov Institute of Oceanology	1987	DNVGL	Rauma-Repola Oy
Russia	MIR 2 *	6000	3	PP Shirshov Institute of Oceanology	1987	DNVGL	Rauma-Repola Oy
China	Deep Sea Warrior	4500	3	China Academie Sciences	2017	CCS	China Ship Scientific Research Center
USA	ALVIN	4450	3	Woods Hole Oceanographic Institution	1964	NavSea	Woods Hole Oceanographic Inst.
USA	PISCES V	2000	3	HURL, Hawaii Undersea Research	1973	ABS	HYCO
USA	PISCES IV	2000	3	HURL, Hawaii Undersea Research	1971	ABS	HYCO

Table 4 – Group 1 “Hadal Depth” Submersibles in 2017

The race for full ocean depth (FOD) capability has abated among philanthropic organizations since James Cameron’s deep dive in 2012. The Deepsea Challenger is not likely to return to operation but China and Japan are hard at work to conquer the deep ocean. Rainbowfish, based out of Shanghai Ocean University, continues its private development of the three-person FOD manned vehicle. In February 2018, CSSRC also announced that the national shipyard was initiating the design and construction of a FOD manned submersible, as well as an unmanned vehicle to reach 11,000m. Japan has no immediate plans for the development of a 11,000m submersible but is working to re-establish its FOD access with a new ROV system, to replace the capability from the unfortunate loss of its 11,000m flagship ROV KAIKO.

In South Korea, KRISO (Korea Research Institute of Ships and Ocean Engineering) a state technology & development agency, has expressed interest in the development of a deep manned

submersible, capable of 6,000m depth. KRISO was established in 1973 with a focus on ship and ocean engineering to develop and commercialize new, original technology. While its primary field is deep sea robotics, it maintains an interest in developing MUV capability, pending government support.

In India, the National Institute for Ocean Technology (NIOT) based in Chennai, is concentrating efforts on developing its own national 6,000m rated manned submersible, the MATSYA 6000. Researchers at NIOT have been working for many years and most of its work has been focused on deployment and operation of a 6000m deep ROV system. This has proven valuable training and learning for the agency which is still working to conclude its contract for the development of its manned vehicle, after several failed attempts. Still, the Indian research center is committed to move forward and bring India into the community of countries with deep ocean research capabilities, motivated by deep sea exploration for resources such as polymetallic manganese nodules, methane hydrates, hydrothermal sulphides and cobalt crusts spread over the 1000m to 5500 m water depth in the Indian Ocean.

GROUP 2 (300- 1000m) Ocean Exploration MUVs

A report by the Rodriguez Group stated that the growth of the global yachting industry in 2017 was near 20% and that this market growth appears to be sustained for 2018. It noted that the average size of large yachts has grown from 47.8 meters in 2013 to 51.6 meters in 2017. This has a direct impact on the market for specialized MUV designs that consider the specific needs of large yacht operations, both for accommodating special owner requests as well as the all-important launch-and-recovery logistics. Table 5 shows the deliveries of yachts over the past five years. While the yachts get larger, the space allocated to MUV storage and staging is all critical and many of the manufacturers have tuned designs specifically for this market.

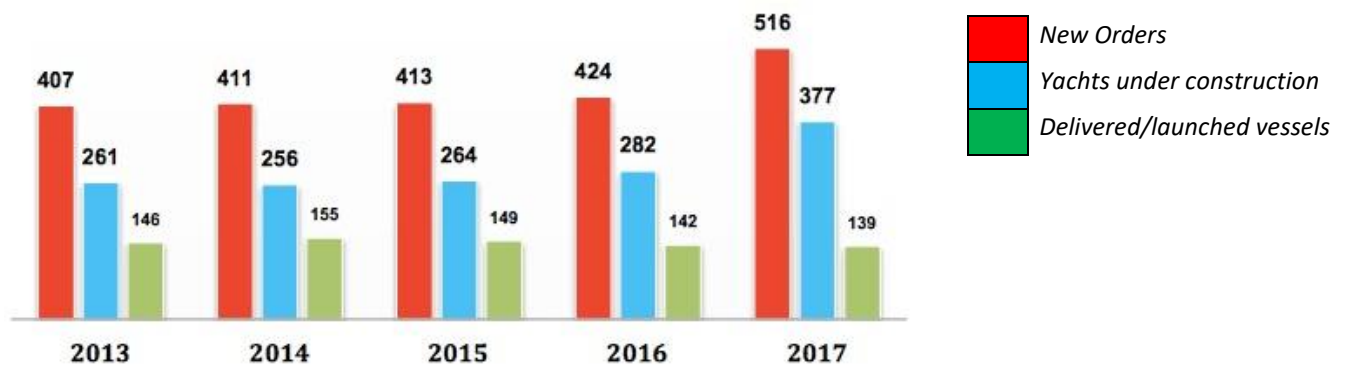


Table 5 – Yachts in production and deliveries 2013-2017 (source – Rodriguez Group 2017)

In 2017, a total of 102 MUVs operate in the Group 2 “Deep Ocean” vehicles, which ranges from 300-1000 meters. Table 6 shows the distribution of the number of vehicles for the different depth

rating of the vehicles. This group is primarily driven by private and commercial operations, including filming, philanthropic research and private leisure operations. However, most of the vehicles in the 360m range represent ADS (Atmospheric Dive Suit) systems used by navies around the world. It is noteworthy that this list includes more than 37 news MUVs delivered in the past 5 years, with an average depth capability of 660m.

GROUP 2 - Active MUVs 300-1000m Depth Range

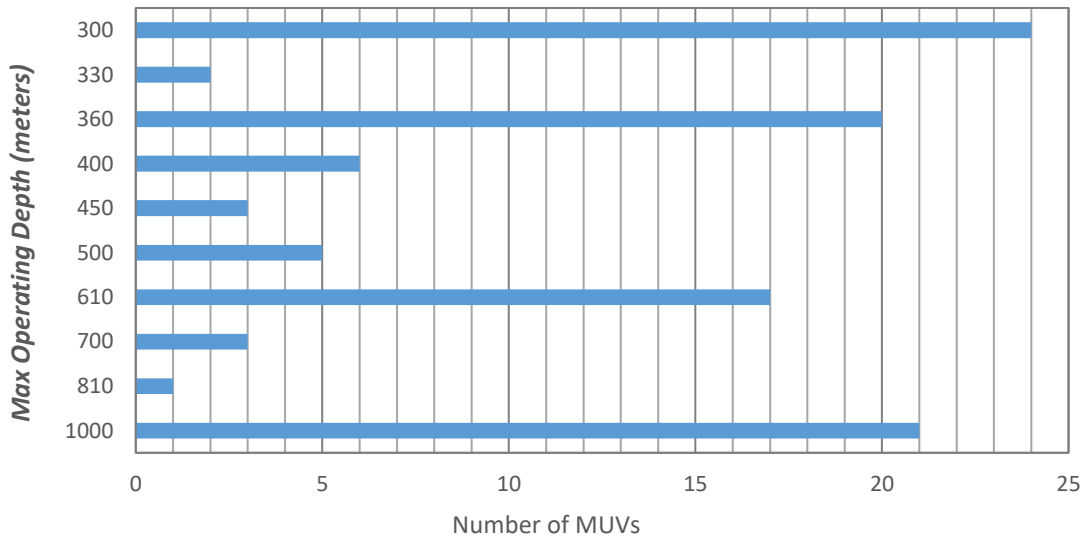


Table 6 – Depth Capacity of Group 2 “Deep Ocean” Submersibles in 2017
 (source – W. Kohnen MUV Database 2017)

GROUP 3 (< 300m) Coastal Ocean MUVs

There are 49 MUVs operating in coastal ocean waters in less than 300 meters, roughly 1/3 of the total active subs in this category. These include many large tourist submersibles, which generally operate between 30 and 40 meters depth. This also includes small private submersibles designed for leisure, commercial work and some research vehicles. The tourism sector is very active, consisting of large 40+ passenger submersibles made by Atlantis Submarines in Canada; and produced by Mobimar, in Finland, accounting for 22 of the 49 vehicles. These vehicles are all highly regulated by both class societies and flag state authorities to ensure passenger safety. Few new large submersibles are being produced due to extensive development of commercially viable locations and the lack of new viable sites. This is an opportunity for any vehicles that can exploit smaller niche markets and novel designs when depth requirements for safety margins are reduced. A new series of tourism operations is planned by a joint venture between Deepflight and Rainbowfish Ocean Technology. Their composite technology models will be launched with LR classification, offering a sufficient but reduced depth rating of 40m for touring expectations and receiving certification for their new materials technology implementation. While non-metallic pressure hulls are not new, they remain on the fringe of Class Society approval due to

challenges in verification and inspection of finished items. Creating mechanisms of approval for new materials is also a rich field for innovation and regulatory expansion.

A few other submersibles with diver lockout capability fall in this group, naturally restricted by diving limits. While it has elicited interest from private users, it has been of primary interest by navies for diver delivery capability. Several new submersibles are in construction for the US Navy as diver delivery vehicles which were designed and developed through a combination of commercial classification and naval rules to streamline cost of production. M-Subs in the UK, Lockheed Martin in Florida together with DNVGL in Germany and NAVSEA found new synergies between commercial and naval regulations in the development of the new S351 seal delivery vehicles (See Submergence Group). This process worked less well for the Navy's DCS-Light concept.

Deep Submergence Rescue Vehicles (DSRVs)

MTS MUV tracks government and military submersible activities, primarily submarine rescue capabilities and technologies. Unmanned capabilities are increasing in scope, but manned submersibles remain at the heart of submarine rescue operations worldwide. The majority operate as autonomous submersibles, capable of docking with a distressed submarine and taking on 12-24 crew members to surface. There are currently 18 DSRV vehicles serving various international Navies. The US Navy operates the PRM1 Falcon system as part of the SRDRS rescue system. It consists of a tethered manned vehicle that interfaces with a surface rescue system installed on a Vessel of Opportunity (VOO) enabling Transfer-Under-Pressure (TUP) from the rescue vehicle to the decompression compartment. The rescue system is maintained and operated by Phoenix International, based in San Diego, California, which is scheduled to test the complete SRDRS system for the first time, including the PRM, TUP and decompression chambers in 2018. Japan, Italy and Russia have developed their own systems and designs. For its part, James Fisher Defence (JFD) has delivered several new rescue vehicles for countries around the world based on its LR5 technology, with its latest model delivered to India last year. China has developed its own submarine rescue vehicles since the 1970s and launched its 7103DSRVs in 1987. Upgraded in 1996, the 7103DSRV were not able to dock with submarines tilted at larger angles and limited to 1.5kt currents. In 2008, China imported the LR7 DSRV, built by Perry Slingsby in the UK, rated to 300m. The Chinese Navy deployed the LR7 during the joint RIMPAC exercises with the US Navy in Hawaii in 2016 and completed exercises with the Russian Navy in 2017. Table 7 shows the DSRV vehicles by country along with general capacity information and year of launch.

No	Country	DSRV Name	Depth (m)	No. Pax	Operator	Year Built	CLASS	Manufacturer
1	AUSTRALIA	LR5 DSRV	400	16	AUSTRALIA Navy	2005	LR	James Fisher Defence
2	CHINA	LR7 DSRV	300	18	China Navy	2008	LR	Perry Slingsby
3	CHINA	Type 7103 DSRV 1a	360	22	China Navy	1987	China Navy	Wuchang Shipbuilding Factory
4	CHINA	Type 7103 DSRV 1b	360	22	China Navy	1987	China Navy	Wuchang Shipbuilding Factory
5	CHINA	Type 7103 DSRV 2a	360	22	China Navy	1987	China Navy	Wuchang Shipbuilding Factory
6	CHINA	Type 7103 DSRV 2b	360	22	China Navy	1987	China Navy	Wuchang Shipbuilding Factory
7	INDIA	DSRV - INDIA	500	16	India Navy	2017	LR	James Fisher Defence
8	ITALY	SRV-300	300	12	Italian Navy	1999	RINA	Drass-Galeazzi
9	JAPAN	JMSDF DSRV 3	700	12	Japan Min. of Defense	2017	NK	Kawasaki Heavy Ind
10	JAPAN	JMSDF DSRV 2	700	12	Japan Min. of Defense	2002	NK	Mitsubishi Heavy Industry
11	JAPAN	JMSDF DSRV 1	700	12	Japan Min. of Defense	1985	NK	Kawasaki Heavy Ind
12	KOREA	LR5K DSRV-I	400	16	Republic of Korea Navy	1995	LR	James Fisher Defence
13	KOREA	DSAR-5 (DSRV-II)	500	16	Republic of Korea Navy	2009	LR	James Fisher Defence
14	Russia	AS-34 DSRV	1000	25	Russian Navy	1989	Russia Navy	Project 1855 - PRIZ Class
15	Russia	AS-28 DSRV	1000	25	Russian Navy	1986	Russia Navy	Project 1855 - PRIZ Class
16	SINGAPORE	DSAR-6	500	16	Republic of Singapore Navy	2010	LR	James Fisher Defence
17	SWEDEN	URF DSRV	450	16	Sweden Navy	2012	LR	James Fisher Defence
18	UK	NATO DSRV NSRS	610	16	BRITISH Royal Navy	2008	LR	James Fisher Defence
19	USA	PRM 1 Falcon	610	16	Phoenix Intl for US Navy	2009	NAVSEA	Oceanworks Int'l

Table 7 – Deep Submergence Rescue Vehicles in 2017

2017 also saw a major submarine accident with the disappearance of the Argentine submarine ARA San Juan, in November 2017. The tragic loss of the submarine with the death of 44 crew members renewed international focus on the limited resources available to support submarine rescue around the world’s oceans. The ARA San Juan was an older type TR-1700-class diesel-electric submarine built in Germany, launched in 1985 and subsequently upgraded from 2008 to 2013. The search for the submarine and crew mobilized ships and aircraft from 18 nations before being called off on November 30 when it was concluded that there was no hope of survivors. The search continued through December using unmanned vehicles to find the wreck. The ARA San Juan remains a mystery and has not been found.



Figure 1 – ARA San Juan Submarine, Argentina Navy

NARCO-Subs

A category of submersible that is not included in the MTS MUV database is that of Narco-Subs: sub-surface vehicles that are often coined as submersibles, but in reality, are semi-submersible vehicles that operate near surface with long range combustion engine power. Used to traffic narcotics for over 25 years, these vehicles receive media coverage when there is dramatic news about seizures and scuttling of vehicles. Figure 2 illustrates the scale of the sea travel problem. This is the 2016 recorded level of traffic between South and Central America for “non-commercial” maritime events, travelling from Colombia and Ecuador to Mexico and Guatemala. The US Coast Guard reported that almost 455,000 pounds of cocaine and heroin, worth \$6 billion, was intercepted in 2017, which exceeded the 2016 record. Nearly 600 suspected smugglers were apprehended by the Coast Guard, up from 465 in 2016 and 373 in 2015. Of course, most of these events do not involve Narco-sub, but it illustrates the context in which their development grows in sophistication.

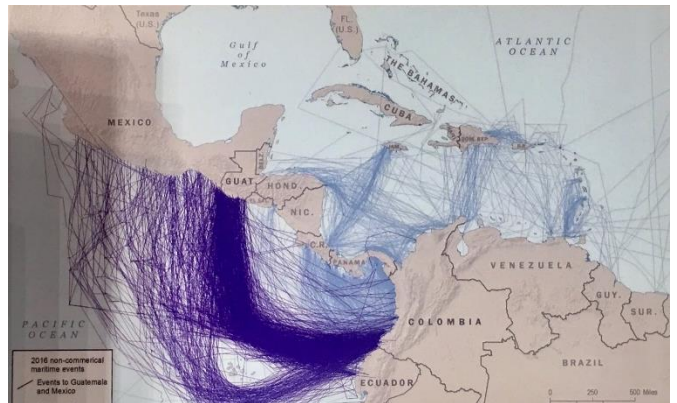


Figure 2 – 2016 Non-Commercial Maritime Events from Colombia and Ecuador to Guatemala and Mexico (source - Business Insider – Sept 2017)

UC3 Nautilus

In August 2017, a UC3 Nautilus “home-made” submarine sank off Denmark in what was revealed to be a grisly crime; the owner-builder of the submarine had deliberately scuttled the vessel after murdering a young reporter onboard. In addition to the horror at the loss of life, the MUV community recognized the potential for damage to the reputation of the submersible community as seen by regulators, insurance companies, individuals and the media. During the investigation, it was widely reported that the submarine was not certified, and even that the owner had “talked about wanting ‘to be free from authorities’ in making his submarines.”¹



Figure 3 – UC3 NAUTILUS Home-made submarine

While this distanced the incident from the MUV submersible industry, the event highlighted the importance of awareness of public, media and regulatory agencies of the differences between amateur, uncertified craft, and those that have been properly certified. The MUV Operations Consensus Standard is an important tool to address this issue.

2018 Manned Overview; alphabetically by Company

Alucia M/V (WHOI)

The Alucia is a private research and exploration vessel, 56m long, with a versatile launch and recovery platform for a wide range of diving and submersible operations. It is equipped with the latest in technical diving, filming and scientific research equipment and contains two subs; Nadir (Triton 3300/3) and the Deep Rover 2 – both of which are rated for a maximum depth of 1000 meters. Alucia conducted 12 missions in 2017 and spent over 200 days at sea with ports of call in Antarctica, Uruguay, Brazil, Cuba, and the US. The Submersible Operations Group completed 84 dives with Deep Rover and 98 dives with Nadir carrying out outreach and scientific objectives. Highlights include dives in Wilhelmina Bay and St. Peter and St. Paul Archipelago. The program is commissioning a new support vessel in 2019 which will be fitted with a man rated A-Frame launch and recovery system.



Aquatica Submarines, Canada

Aquatica Submarines is a Canadian based submersible manufacturer that provides design, manufacturing, sales and operations of manned submersibles. The company's Stingray 500 is a light displacement three-person, acrylic hull, classed by DNVGL and rated to 500 feet depth. Throughout 2017, Aquatica's team of pilots operated the submersible in the coastal waters for Vancouver, Canada to conduct a range of dives and expeditions. Dive missions included tourism operations with tier one tour providers, scientific research and biological monitoring of artificial reefs, commercial surveys, and several film and media expeditions. The company provided dives and lectures for the TED 2017 Convention in the waters off Vancouver, Canada. It also used its submersible film a subsea commercial featuring 360 technology with Samsung products, scheduled to air in early 2018, and was featured on the Discovery Channel's "Daily Planet and Tech Week."

Aquatica’s Stingray 500 was used to conduct a series of dives for Canadian research organizations including the Underwater Council of British Columbia, The Artificial Reef Society of British Columbia, the Marine Life Sanctuaries Society and the Vancouver Aquarium. One of the expeditions resulted in the discovery of a large Glass Sponge reef previously unknown to scientists and was featured on Discovery Channel. The Glass Sponge discovery renewed interest from conservation groups and the public. In response, Aquatica developed a 360 Virtual Reality (VR) experience to facilitate education and stewardship to be made available through social media outlets for National Geographic. Aquatica’s regular diving schedule also focused on Sixgill sharks in Canadian coastal waters and continues to work closely with scientists to film and showcase this species.



The company has signed new contracts for the design and manufacture of a series of underwater vehicles that to include the standard 500 ft rated model and add a new 1000 ft (305) model. In addition to the deeper submersible design, Aquatica also plans to launch a new line of transport vehicles designed to reduce costs associated with submersible operations, transport and delivery. The Company is scheduled to launch the new vehicles in 2018.

Bulgaria Academy of Sciences (BAS), Bulgaria

PC8B is a three-person, 250m rated Perry Submersible, launched in 1971, and operated by the Institute of Oceanology, Bulgarian Academy of Sciences (IO-BAS), located in Varna, Bulgaria. IO-BAS is a national research center using the submersible for interdisciplinary monitoring of the Bulgarian part of the Black Sea basin.

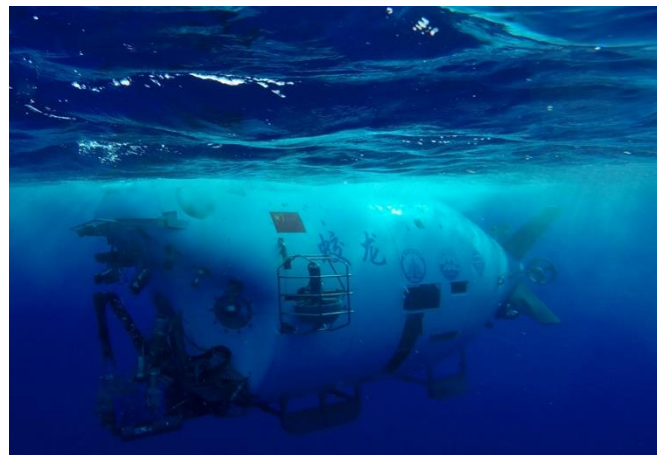


Dr. Ilko Shtirkov reported that in 2017 the director of the Institute, who strongly supported the UW activities, passed away. The new director, faced with budget shortages cut all planned expeditions and is working on the re-fit of their support ship “Academic” to renew its 5-year Class certificate from Bulgarian Register of Shipping. It is expected to take a year to organize the refit.

The submersible obtained its 5-year Class renewal but performed only a single dive in 2017 to take a water sample from the geothermal spring, which was discovered at 140 m depth several years ago. Researchers were surprised that the spring had stopped its activity, possibly due to several earthquakes that took place in the region. The institute is challenged to find a new pilot to continue the subsea research as government budgets for science have been severely cut for 2017 and 2018 and most expeditions operate in joint projects funded by European Union.

China National Deep Sea Center (NDSC), P.R. China

China National Deep-Sea Center (NDSC) is based in Qingdao and is the home of JIAOLONG, China's 7000m rated deep ocean research submersible. JIAOLONG is owned by the China Ocean Mineral Resources R&D Association (COMRA) and the NDSC research center is operated by the China State Oceanic Administration (SOA). JIAOLONG is a three-person submersible designed and built by the China Ship Scientific Research Center (CSSRC) and classed to the China Classification Society (CCS). Named after a mythical dragon, JIAOLONG is China's first manned deep-sea research submersible, developed by Chinese designers starting in 2002. During a test dive in June 2012, JIAOLONG reached its deepest depth - 7,062 meters - in the Mariana Trench. Since January 2013, the submersible has made a total of 152 dives.



The submersible's mother ship, Xiangyanghong 09, returned to the National Deep-Sea Base in Qingdao in June, 2017, ending the 38th oceanic expedition and the submersible's five-year trial phase. During the 138-day expedition that started on Feb 6, JIAOLONG and its mothership sailed nearly 34,000 kilometers into the South China Sea, northwestern Indian and northwestern Pacific oceans. JIAOLONG conducted 30 dives for scientific investigations and collect samples. Researchers from the State Oceanic Administration, Ministry of Education, Chinese Academy of Sciences and China Geological Survey dove with the JIAOLONG to collect 625 kilograms of seabed rocks, 5,968 liters of seawater as well as 2,115 marine creatures. During the expedition, the submersible made five dives in the Mariana Trench and the Yap Trench, both in the western Pacific Ocean. These dives were organized for scientists to better understand the trenches' geochemical and biological conditions.

After the mission, JIAOLONG is scheduled for a yearlong overhaul and technical upgrades. The submersible is planned to start its formal operation phase in 2018 designed take the submersible farther away on expeditions.

China Ship Scientific Research Center (CSSRC), P.R. China

CSSRC is China's largest ship and ocean engineering research institute with 500+ research engineers for the research of ship design and high performance underwater engineering. CSSRC has worked on the development of submersible technology since 2002 when it started the design of the 7000m rated JIAOLONG submersible. It was developed with a combination of national and international technology and completed its certification in 2012 to become the deepest operating research submersible today. Afterwards, in 2015-2016, CSSRC developed and launched two new acrylic-hulled tourist submersibles, the Huan Dao Jiao Long 1 and 2, rated to 40m for 7 passengers + two crew, for commercial operation on Hainan Island. The focus of its progression aims at developing an increased national capability of submersible technology.



Deep Sea Warrior - 4500m, Research



Huan Dao Jiao Long 1 & 2 – 40 m, Tourism

In 2017, CSSRC completed China's newest manned submersible, named Shenhai Yongshi, or Deep-Sea Warrior. It was officially delivered to the Academy of Sciences in November 2017 designated to serve China's dynamic marine scientific research programs for the next 30 years. The new submersible is a three-person vehicle rated to a depth of 4,500 meters. Among its major features is the fact that it is 95% national technology content. Major domestic components include the personnel sphere, underwater acoustic communication system and acoustic Doppler velocity log instruments. The Deep-Sea Warrior has been eagerly awaited by scientists in China to increase deep ocean access capacity. The completion of this submersible also helped expand the technology foundation for the next vehicle. CSSRC announced that its next project will be the

development of a full ocean depth manned submersible. The FOD vehicle is currently under construction at the shipyard in Wuxi, near Shanghai. The plan also includes the parallel development of a new unmanned vehicle capable of full ocean depth. China's Haidou 1 unmanned vehicle helped set a hadal technology foundation when it dove to a depth of 10,767m near the Mariana Trench in 2016. During the trip the AUV made two dives to 9,000 meters and twice to 10,000 meters. This made China the third country after Japan and the United States to have reached deeper than 10,000 meters. Both vehicles are scheduled for completion by 2020.

China Deep Submergence Rescue Vehicle, P.R. China

China's development of DSRVs started in 1971 at the Wuhan Shipbuilding Factory with the design of the Type 7103 vehicles. Construction of Type 7103 DSRV begun in 1976 and was launched for initial sea trials January, 1980. Engineering developments and tests continued through when final tests were conducted for deep diving, wet and dry rescues. The design included a crew of 4 with the capacity for 22 sailors. The vehicle weighed 32T and was rated for a maximum rescue depth of 300m, later overhauled to 360m. The power system was based on silver-zinc batteries. The Type 7103 DSRV was formally handed to PLA Navy (PLAN) on November 1987. A total of 4 Type 7103 DSRVs were built, with two vehicles in operation at any given time. The DSRVs are supported by Type 925 Dajiang class ASR/ARS ship that can carry two DSRVs during rescue missions. The Type 7103 were overhauled in 1996 to improve its positioning system, new electronics and increase its rescue depth rating to 360m.

In 2008, the PLAN (People's Liberation Army Navy) imported the LR7 DSRV. It was put in service in 2009 and was intended to modernize the navy's submarine rescue capability from its 1970's-based technology of the Typ3 7130 DSRVs. LR7 was constructed by the British firm Perry Slingsby System, a development of the earlier LR5 submersible. The LR7 is 25 ft long, capable of rescuing 18 sailors per trip and rated to a depth of 300 meters. The battery charge allows for 12 hours operation before recharging.



The Chinese navy (PLAN) participated for the first time alongside the navies of twenty five countries, including the US Navy in July 2016 during the RIMPAC submarine rescue exercise off Hawaii. The LR-7 was deployed from the mothership Changdao and it docked with a simulated

underwater submarine wreck. This was a milestone in Sino-American naval relations. In 2017, LR7 participated in the “Joint-Sea 2017” Sino-Russian exercise which took place in the Sea of Okhotsk in September 2017. The exercise conducted the first underwater mating of the LR7 rescue vehicle with a Russian submarine simulating a disabled boat on the sea bed.

DEEPFLIGHT, USA

DeepFlight continues its legacy of innovative underwater technology to enable underwater flight. DeepFlight submersibles are winged submersibles designed to be “positively buoyant,” and use hydrodynamic forces from the wings to push the vehicles underwater when moving. The submersibles are low displacement, light weight, designed for speed for commercial markets of superyachts, luxury resort and private ownership.



In 2017, after many years of self-certification, the company has been working with Lloyds Register to class the new DeepFlight series of submersibles. This classification allows DeepFlight to innovate using composites and other advanced materials, which provide the strength to weight ratio to introduce their new generation of lightweight submersibles. DeepFlight launched its new Super Falcon 3S submarine, a 3-person (1 pilot, 2 passengers) craft designed for tourism operations. Super Falcon 3S is based around a composite hull vehicle classed by Lloyds Register rated to a depth of 40 meters. The company reported survey of component parts have been undertaken in the UK and the USA, alongside the auditing of fabrication facilities. Both the prototype and production hulls have been successfully pressure tested, and final sea trials of the first of the Classed units are taking place in the Maldives in early 2018.

The first Super Falcon 3S is scheduled to be operational in the Maldives in Q1 2018, offering submarine excursions at a luxury Five Star resort. A trained pilot will take up to two guests at a time on underwater flights directly from the resort property. Laucala Island in Fiji is also operating an original Super Falcon 2-person submersible for its resort guests. The company plans to continue expansion of its DeepFlight Adventures to other locations, in partnership with resorts, tour and water sports operators.

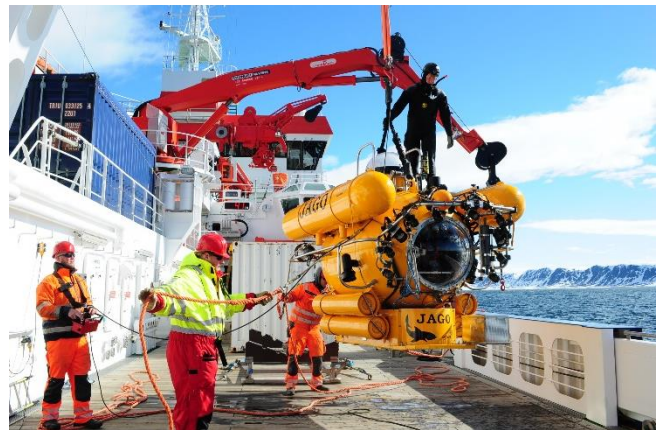
DeepFlight is also continuing to sell its submarines to private owners, and in particular, the superyacht market. In 2017, Princess Yachts ordered a DeepFlight Dragon to be integrated into a new build of its 40m M class yacht. As the smallest and most lightweight 2-person submarine on the market, Dragon is one of the only personal submarines that can fit on smaller yachts with little or no need for retrofit.



In addition to opening its first location for DeepFlight Adventures in 2018, the Company will also be building several submarines for delivery in 2018-2019.

GEOMAR Helmholtz Centre for Ocean Research, Germany

JAGO is a 400 m depth rated 2-person submersible dedicated to research in marine sciences, stationed at the GEOMAR Helmholtz Centre for Ocean Research and is presently the only manned research submersible in Germany. The submersible's relatively light weight (3 tons) and its compact size (3 x 2 x 2.5 m) make it easy to operate worldwide and from a wide variety of support ships that have sufficient crane capacity. JAGO was built in 1989, is DNV-GL classed and has made more than 1300 dives around Europe and Africa.



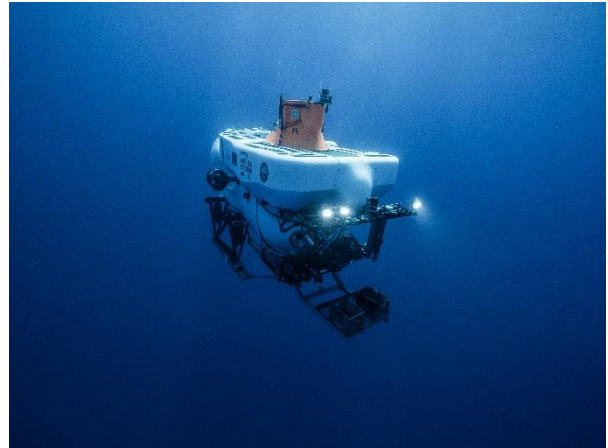
In 2017, JAGO has undergone a general overhaul including numerous test dives in the Kiel fjord with the exchange of new instruments and components. The JAGO team is also replacing its thrusters to a rim drive system. In February-March 2018, JAGO went on a research cruise to the Cape Verde islands to study midwater biodiversity and ecology. The Cape Verde islands are considered a perfect location because the deep sea is close to the islands and pelagic organisms from deep water can be found both close to shore and in shallower waters. Researchers reported making 15 dives down to 400 m depth in the lee sides off the islands Santo Antao and Fogo.

Through 2018, the team plans to exchange its rotatable side thrusters and prepare sampling devices and instruments in preparation for the next two JAGO campaigns scheduled to take place

in summer from on board the RV POSEIDON. From end of June to mid-July 2018, JAGO will dive at the cold water coral reefs off Norway and from mid-July to mid-August in the North Sea and in the Skagerrak - a new technology testing project that combines submersible dives with hover AUV surveys.

Hawaii University Research Lab (HURL), USA

The Hawai'i Undersea Research Laboratory (HURL) is part of the School of Ocean and Earth Sciences and Technology at the University of Hawai'i and has been providing unique deep ocean research capabilities for nearly 40 years. HURL specializes in both research tools and expertise for scientific investigation of the undersea environment. This includes a unique set of manned submersibles, remotely operated vehicles, and other deep-sea technologies. Most notably, HURL operates the twin Pisces IV and PISCES V deep submersibles which are

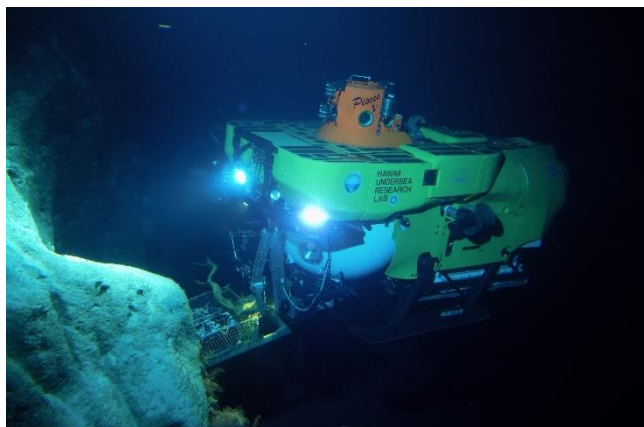


among the longest operating submersibles in the industry. The submersibles are three-person vehicles rated to a depth of 2000m and are ABS classed. The deep diving submersibles are the only US deep ocean national asset that provide the versatility of operating two submersibles side-by-side. The strategic and performance advantages of such an operational concept has been proven time and again, just as did the Russian MIR submersibles in a wide range of unique expeditions.

The university center has faced challenges since NOAA defunded its submersible program in 2014, but the team has continuously demonstrated creativity and innovation in the service of research. To increase productivity and bottom time per dive day, HURL has transitioned to a default dual sub dive model with its PISCES IV and PISCES V submersibles. The ingenuity of this approach is to boost productivity by getting more work done in fewer days at sea.

Large support vessels are required for both manned or unmanned systems, and it has become clear that deep ocean ROV operations have their own challenges when used for deep exploration. The key element for research remains productivity, the ability to get the same level of work done in less days at sea, or getting more coverage in the same amount of days. The HURL Team has successfully shown over two seasons (2016 & 2017) that twin manned submersibles offer undeniable productivity gains over unmanned ROV systems.

The 2017 NSF funded Deep Coral Ecosystem Recovery Assessment Project in the Northwestern Hawaiian Islands and Southern Emperor Seamount Chain is an exemplary testimony of MUV mission success. The \$3.5M project allocated 90 ship days of which 25 days were used in transit, a total of nearly 4,500 nm. An additional 10 days were lost to unexpected weather outside normal launch margins. The original plans were to explore the terrain by ROV.



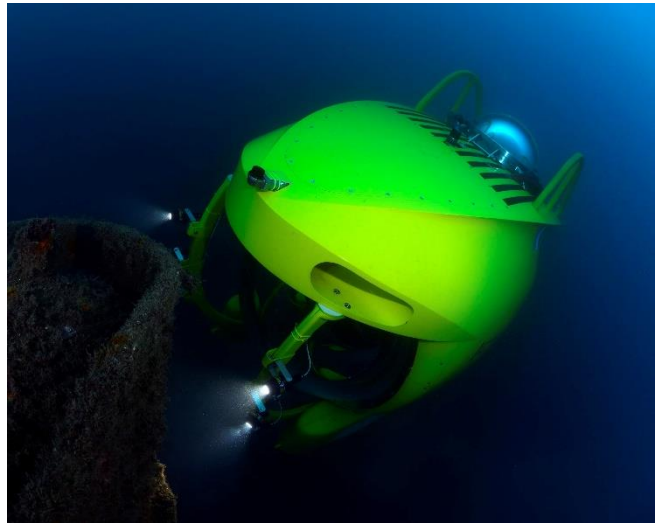
However, the topography consisted predominantly of current swept, steep volcanic island cores and vertical carbonate atoll walls with numerous narrow cutbacks and overhangs. Danger and risk was unnavigable for all but the most advanced robotic underwater systems and teams. By mid-November 2017, the survey was successfully completed using the twin PISCES submersibles and the HURL team. They availed themselves of the remaining 55 work days to perform a total of 76 submersible dives during which 242 detailed bottom video transects of 500m each were completed. A total of 1,533 coral samples were collected for genetic and paleo-oceanographic analysis. The total distance covered by the two subs was about 250 km, the average time submerged per dive day was 12 hours, and the average time spent on bottom transecting and collecting was 8 hours.

At the beginning of 2018, the University announced that it would shut down the submersible operations and divest itself of the assets. The KOK research ship is due for re-certification by mid-2018 while both submersibles remain in ABS Class. The two PISCES submersibles represent the only US asset capable to deploy a tandem team of submersibles to 2000m, with an operations team presenting more than 25 years' experience operating MUVs. This remains a unique asset in the US roster of national capabilities. The HURL reports multiple standing projects for 2018 for the two submersibles. The de-commissioning of these assets would reduce US national capabilities to a single MUV (ALVIN) capable of deep submergence and stand in contrast with international capabilities and developments.

ICTINEU Submarins SL, Spain

Ictineu Submarins is a manufacturer, operator based in Barcelona, Spain, founded in 2007 to develop and build the deepest private submersible in operation, the ICTINEU3. This new generation of manned submersible, with a powerful state-of-the-art battery package, can navigate up to 20-nautical miles underwater. The ICTINEU 3 is designed for underwater exploration, scientific research and underwater intervention. ICTINEU innovations include advanced hydrodynamics, extensive use of smart composites and high-density high-power lithium batteries capable of operating at ambient pressure. Ictineu 3 was classed by DNVGL and launched in 2013 and is registered by French Maritime Affairs for operation in European waters. ICTINEU 3 has completed more than 100 dives at sea between 30 and 1,000 meters depth.

In 2017 ICTINEU deployed their submersible for an expedition to the Nice canyon in Côte d'Azur, France. The expedition was organized in cooperation with the Oceanographic Observatory of Villefranche sur mer (OOV – CNRS – UPMC) and the research laboratory Géoazur, France. The Oceanographic Observatory of Villefranche is a multidisciplinary research center associated with the University Pierre et Marie Curie in Paris and the French National research institution CNRS. The mission took plankton observations through the water column, studied the crepuscular benthic communities as well as coral communities and their relationship to water acidification.



The Géoazur center combines Earth, Ocean and Space research. Three subjects of particular interest were 1) the Messinian Era in which the Mediterranean basin (sea) dried out and afterward re-filled quickly; 2) a study of the -120m zone where the sea level was during the last glaciation; and 3) an evaluation of the geologic risks on the Nice airport, which is located near a highly abrupt shelf. The team observed very steep terrain, even steeper and more abrupt than shown by the detailed cartography. Near the seafloor very dense masses of plankton and krill were observed. Observations confirmed that some species of plankton are abundant in the area, although they are rarely sampled with the usual sampling tools.

In early 2018, the company announced the successful development of the first battery module certified for operation at full ocean depth in a joint venture with Triton Submarines. The new

unit, a pressure-compensated Lithium-polymer battery module producing 148V DC, 10,36kWh was developed to extend ICTINEU's existing 6,700m-rated power unit to a battery capable of diving to any depth, from shallow to full ocean depth. ICTINEU reports the unit is currently undergoing DNV-GL Type-Approval, the new battery named ITHACA is a maintenance-free, 4,000 cycle capable plug-and-play battery. Full production of ITHACA is on schedule first deliveries in mid 2018.

IFREMER Nautille, France

IFREMER built Nautille in 1984 and it was the first of a new generation of deep research submersibles rated to 6000m. Nautille counts among its achievements 116 dives on the RMS Titanic between 1987 and 1998, early thermal vent exploration and meeting up with ALVIN at the bottom of the Atlantic in 1987. While budgets are strained IFREMER has no plans to replace NAUTILLE and projects an extended life program for the pressure hull and periodic technology improvements.



Nautille remained active through 2017 with a scientific expedition on the Mid-Atlantic Ridge from March-April 2017 aboard the research ship Pourquoi Pas?. During this expedition Nautille performed 20 dives to depths ranging from 3500-4500m. In December 2017, Nautille was deployed on a technical expedition in the Mediterranean. A series of engineering dives to depths of 2700m were performed to prepare the submersible for its 2018 season with a series of new and advanced scientific instruments designed for taking samples and perform in-situ analysis.

In January 2018 Nautille was deployed in the Mediterranean for work on the subsea neutrino detector observatory, ANTARES, located at a depth of 2500m. This is the European equivalent to the North American Sudbury Neutrino Observatory (SNO). The Nautille performed work at the base of the detector field for the recovery of certain scientific instruments.

In February-March 2018, Nautille is scheduled to return to the Mid-Atlantic Ridge for a biological exploration of the hydrothermal vents and has planned 28 dives between 3000-4000m depth. The submersible is scheduled for maintenance between April-August 2018, which will include the replacement of the equatorial o-ring sealing the two hemispheres of the personnel sphere. At the end of the year, Nautille is scheduled to be deployed on the site for a new underwater

observatory called MEUST, which is to replace the existing ANTARES observatory. The Nautilie will be used to install and deploy new scientific equipment.



France Deep Submersible NAUTILIE launched from its mothership Pourquoi Pas?

JAMSTEC Shinkai 6500, Japan

Shinkai 6500 is the flagship deep ocean submersible for the Marine Technology and Engineering Center of JAMSTEC (Japan Agency for Marine-Earth Science and Technology). Shinkai 6500 was built in Kobe Japan in 1989, a three person deep ocean research submersible rated to a maximum depth of 6500m. The SHINKAI 6500 is operated from its mothership R/V Yokosuka and passed the 1500 dive mark in 2017, completing its 1509th dive during the season.



The Shinkai 6500 had a major overhaul in 2012, the largest upgrade made to the submersible since it was launched. JAMSTEC has initiated a second major upgrade, specifically addressing the remodeling of the personnel sphere. The Shinkai 6500 was traditionally piloted with a pilot, a co-

pilot and one passenger/researcher. Demands from scientific communities are continuously evolving and one requests was for two researchers to be able to dive together, with a single pilot. While this has been a traditional operating concept in other countries, JAMSTEC had to make changes to design, instruments and concepts of piloting to transition to single pilot operation.

A major remodeling was carried out from 2016 to 2017 to realize the single pilot changes. The cabin remodeling and overhaul was completed in March 2017. New equipment and instruments had been installed and checked throughout the previous year to help with navigation and operation. JAMSTEC performed several dives in 2017 which allowed shakedown training conducted under simulated one-man pilot operations. Some of the principal operational issues to transition as a single pilot is the concurrent operation of the HDTV camera, Operation of the robotic arm to take samples, talk to the surface ship and manage the recording of the samples taken. Several challenges were extracted from the exercise and final equipment improvements were made for 2018. JAMSTEC is revising its operation manual and confirms that single-pilot operation is no hindrance. From April 2018 onwards, JAMSTEC plans to start single pilot operation for research dives at well-known research locations.

Japan Maritime Self Defense Force, Japan

In September 2017, Kawasaki Heavy Industries launched JMSDF's third deep submergence rescue vehicle (DSRV) built for the Japanese Ministry of Defense (MOD). This vehicle is the 3rd DSRV, and it has been 18 years since the 2nd DSRV was delivered in March 2000. Unlike airplane accidents, submarine accidents often have survivors and rescuing the crew of a disabled submarine is a major concern of modern navies in the world. This technology is



more closely related to deep research and commercial submersibles than military submarines. Common traits are the deep depth of operation, its operating crew, the ability to accommodate a large number of occupants with the ability to reach a stricken vehicle and mate to its rescue hatch.

The Japan Maritime Self-Defense Force is the de facto navy of Japan and the new DSRV launch is part of an effort by JMSDF to modernize its undersea capabilities with a fleet of 22 diesel-electric submarines by the early 2020s. This includes a total of 12 new Soryu-class submarines by 2021,

with a displacement of 4,100 tons when submerged and Japan's first class of air-independent propulsion submarines. The JMSDF is one of the world's largest navies and the second largest navy in Asia in terms of fleet tonnage. Japan will also become the first nation to equip part of its submarine fleet with advanced lithium-ion batteries, one of Japan's top military secrets, in order to improve the submarine's underwater endurance.

Inspired by the Russian Kursk incident, NATO established the International Submarine Escape and Rescue Liaison Office (ISMERLO) to help for global assistance in submarine accidents. At the same time, with the growing number of nations operating submarines over the past 25 years, the philosophy of collective rescue spread rapidly. Today, many countries collaborate to offset the high cost of developing these submarine rescue capabilities. Multilateral at-sea exercises such as Sorbet Royal bring together NATO members and Pacific Reach brings participants of Asia-Pacific nations. Japan continues to participate in these exercises since the early 2000's. Japan's native submarine production technology and deep submersible capability present a growing national asset as it now seeks to export its technology around the world. Although coordination and standardization challenges exist, in general the NATO countries enjoy a closer working relationship than does the pacific theater. China, Japan and India face greater challenges balancing international cooperation with national security.

JFD / James Fisher Defence, UK

JDF is Headquartered in Inchinnan, near Glasgow, and has over 30+ years of submarine rescue operation experience with facilities in Singapore, Australia and Sweden. It has established itself as an international specialist in this field. JFD provides design, manufacture, maintenance, training services. JFD provides submarine rescue capability to several countries, including the Submarine Rescue Vehicles (SRV) for the Indian navy.

In Fall 2017, experts from nine allied nations committed submarines, submersibles, rescue vessels, specialist medics, helicopters and divers for a two-week long Exercise Dynamic Monarch. Taking part in the exercise was the JDF built NATO Submarine Rescue System (NSRS), jointly owned with UK, France and Norway, capable of diving down to a submarine in distress, "mating" with escape hatches and carrying out an evacuation of the vessel. Submersible from 11 countries participated in exercises to depths of more than 720ft. The NSRS like many rescue submersibles can be transported anywhere in the world within 72-hours.



JFD Submarine Rescue Vehicle – DSRV I for India Navy

JFD Submarine Rescue Vehicles

SRV	Nation	Max depth
LR5 (DSAR-1)	Australia	400msw
DSAR-5	South Korea	500msw
DSAR-6	Singapore	500msw
NSRS SRV-1	NSRS	610msw
URF	Sweden	450msw
INDIA DSRV I	India	620msw
INDIA DSRV II	India	620msw

In 2017 JFD completed harbor acceptance trials for the first of two DSRVs for the Indian Navy. These two DSRVs are part of a 3rd generation submarine rescue system developed by JFD to rescue the crew from a distressed submarine (DISSUB). The DSAR class Submarine Rescue Vehicle is capable of diving to deeper depths than previous designs with a crew of 3 and up to 17 rescuees. Under a £193m contract, awarded in March 2016, JFD is providing two complete flyaway submarine rescue systems including DSRVs, Launch and Recovery Systems (LARS) equipment, Transfer Under Pressure (TUP) systems, and all logistics and support equipment required to operate the service. The full certified systems are scheduled to be delivered to the customer in June 2018.

NASA (National Aeronautics and Space Administration), USA

NASA’s Cassini space probe was the first satellite designed to orbit around Saturn. Until then, very little was known about the its moons, including Titan, its largest moon which is roughly the

size of Mercury. Cassini mapped the moon's surface and even sent out a probe, called the Huygens probe, to the surface of the moon. The discoveries were extensive. Data from Cassini-Huygens probe revealed Titan has seas of liquid methane and ethane. In 2008 the 400,000sq km ocean was named Kraken Mare and thought to be the largest body of liquid on Saturn's moon. The temperature of the methane ocean is -184 degrees Celsius. Today, NASA is studying possibilities of exploring Titan's oceans with a specially designed submersible vehicle.

NASA believes that there may be life on Titan as it is the only place in our solar system where surface liquids have been found, and where there is water, there is chance of life. The proposed submersible would be designed as an autonomous research and science vehicles aimed at the study of extraterrestrial seas.

Several probe ideas have been proposed and NASA is considering a fully autonomous submersible. The space agency has a conceptual design for the Titan Submarine and is looking at a mission challenge within the next 20 years. Titan is 886 million miles from Earth, so it would require a significant spacecraft to get the submarine to destination. One of the challenges operating a submersible vehicle in such cold environments is the problem of bubbles. Any system based on heat generating machines is likely to generate nitrogen bubbles which can lead to maneuvering problems.



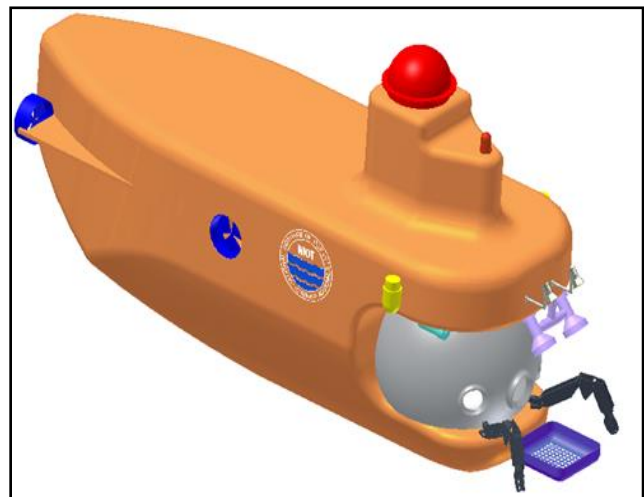
Nasa says: "By addressing the challenges of autonomous submersible exploration in a cold outer solar system environment, Titan Sub serves as a pathfinder for even more exotic future exploration of the sub-surface water oceans of (Jupiter's moon) Europa." If such a mission moves forward, it would represent a new frontier of space exploration as well as research submersibles.

NIOT (National Institute of Ocean Technology), INDIA

The National Institute of Ocean Technology (NIOT) was established in November 1993 under the Ministry of Earth Sciences, Government of India, based in Chennai. The institute's primary aim is to develop indigenous technologies for deep ocean exploration and the harvesting of non-living resources such as polymetallic manganese nodules, marine gas hydrates, hydrothermal sulphides and cobalt crusts. These resources are typically found between 1000 and 5500m water depths in the Central Indian Ocean Basin, Bay of Bengal and Arabian Sea.

Over the past 20 years, NIOT has developed several underwater vehicles. These include a 6000m depth rated Remotely Operated Vehicle (ROSUB 6000) qualified and tested to 5289m in the Central Indian Ocean Basin. The ROV reconnoitered for natural gas hydrates at depths of 1000m in the Krishna Godavari basin, polymetallic nodules at depths of 5000m in the Central Indian Ocean Basin and hydrothermal sulphides at the Rodriguez Triple Junction in the Central Indian Ridge system at a depth of 2813m. NIOT also developed other submersible systems such as a 6000m depth rated in-situ soil tester, a 3000m depth rated Autonomous Coring System, and a 500m depth rated underwater integrated mining system. For polar research, NIOT also developed a 500m depth rated remotely operated vehicle (PROVe).

The next step in the development is to utilize the expertise gained over the past two decades to develop a deep ocean Manned Submersible - MATSYA 6000, with a depth capability of 6000m. The NIOT MATSYA 6000 is designed for carrying three persons with an operational endurance of 12 hours and emergency endurance up to 72 hours. The design follows a traditional architecture with the objective to leverage the newest technologies to keep the submersible weight less than 20 tons. The 6000m rated cabin is based on a 2.1m diameter titanium alloy personnel sphere, made of two halves welded together. Hydrodynamics are aimed at achieving ascent and descent rates of 30+ m/minute, allowing the submersible to reach full depth in three hours. Study work continues on view ports, life support systems, reliable battery configuration, and launching and recovery systems.



No manned underwater vehicle systems currently exist in India. NIOT continues to develop expertise and capacity in the development of India's manned submersible technology with possible joint partnership of national and international organizations.

Nuytco Research Ltd., Canada

Nuytco Research Ltd builds a wide range of manned submersibles in North Vancouver, Canada. The submersibles include the single occupant Deepworker and two-person Dual-Deepworker vehicles rated to 600 and 1000m, a five-person tourism submersible Curasub, and the Orcasub

personal vehicle. Nuytco also manufactures the EXOSUIT, an advanced version of the NewtSuit which are Atmospheric Dive Systems (ADS) designed and classed to Lloyds Registry.

In 2017 Nuytco made several expeditions, sending submersibles to Brazil and diving for a month at the mouth of the Amazon River. Later in the year, Nuytco completed a contract in California for fisheries research. At the beginning of 2018, a full crew and two DeepWorkers went on a month-long expedition in Antarctica for Greenpeace, until the first week of February. Greenpeace released many photos and video clips as it called for a large ocean sanctuary for the newly discovered habitat. Greenpeace, based in Amsterdam, is calling for a sanctuary area covering 700,000 square miles (1.8 million sq km) to be set up in the Antarctic to keep species including whales and penguins safe. Proposals for the sanctuary have been submitted by the EU and to be considered when the Antarctic Ocean Commission convenes in October 2018.



Nuytco also reported working for ONR (USN) on a new version of the submarine rescue system that was originally designed and built for the USN and Australian Navy based on a new large, all-electric work-class ROV, called the NewtROV, adapted to accept a one-atmosphere personnel conveyance system.

OceanGate Inc., USA

OceanGate Inc. is a privately held company in Washington State established in 2009 for the development, manufacture and operation of manned submersibles for commercial, scientific and tourism projects. OceanGate owns and operates the 5-person Antipodes MUV rated for 300 meters depth and Cyclops 1, a 5-person submersible rated to 500m. The main thrust of the company's activity is the development of a next-generation experimental based on composite materials, for deep ocean operation. Developed as Cyclops 2, the new submersible was launched



at the end of 2017 as TITAN, design for a depth of 4000m with space for 5 occupants. The focal point of the new design is a composite laminate pressure hull, a large acrylic viewport and a specialty designed launch and recovery platform for both near-shore and offshore operation.

TITAN features a single, large viewport and its carbon fiber and titanium construction is designed to make the submersible lighter than traditional deep-sea submersibles. It will be outfitted with external 4K cameras, multi-beam sonar, laser scanner, inertial navigation and an acoustic synthetic baseline positioning system. In parallel with the new submersible development, OceanGate plans to mobilize a new subsea launch and recovery platform. The two elements are intended to work in tandem to form the TITAN integrated diving system. The platform will be used to launch and recover the sub and serve as a floating platform for service and maintenance. The integrated system is designed to eliminate the need for A-frames, cranes and divers allowing expedition crews simpler, low cost deployment option in remote locations.

TITAN was launched in February 2018 in the waters around Everett, Washington, where it is to be tested for two months in a series of engineering dives to nominal depths < 300 meters. TITAN is an experimental design incorporating the largest carbon fiber and titanium pressure vessel, the first ever constructed for external pressure, therefore factory testing and validation program is critical. The company has invested six years of design and testing of this pressure vessel design in partnership with technology organizations such as the Applied Physics Lab at the University of Washington and the Boeing Company. OceanGate reports this has given the company full confidence in their novel approach which incorporates a hull monitoring system design to determine the early onset of hull failure and detect potential longer-term fatigue and undetected damage over the life of the pressure vessel. This system is based on nine separate acoustic sensors and eighteen strain gauges to measure all mechanical loading of the hull using both passive and active measurements to compare with historical performance at depth. The objective is active monitoring to permit more efficient designs, requiring lower safety factors than used in traditional design techniques and thereby saving weight.

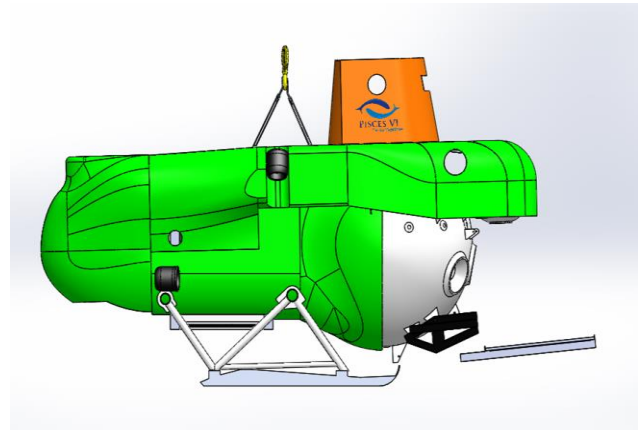
Due to the non-conventional nature of the design, OceanGate is not pursuing classification by IACS Class societies. Instead, it has developed a test program modelled on the aircraft test industry where performance envelopes are systematically increased based on a thorough review of performance data from prior tests. While in the Bahamas, the factory acceptance tests are scheduled to conduct multiple dives to 4,000 meters to validate the operations and robustness of its hull design with real time hull health monitoring, its large viewport, the control, propulsion and battery systems, sonars, laser scalars, its inertial navigation system (iXBlue Phins INS), 4K cameras and other systems. OceanGate reported that the deep diving will be tested gradually towards its goal of 4000m, ascertaining the health of all components and systems before diving

deeper. The company acknowledged that if unexpected limitations are encountered during the trials, the submersible could be de-rated to a level deemed safe by its engineering department.

TITAN was transported to Marsh Harbour in the Bahamas for deep water testing in late April 2018. The transport and rough weather during the transit caused both damage to the submersibles electronics and caused delays to the testing schedule. The company announced in May that due to these delays the 2018 planned Titanic Survey Expedition would be postponed.

PISCES Submarines, USA

PISCES VI is a sister vessel to PISCES IV and V operating in Hawaii. The submersible was acquired by Pisces Submarines in 2015, located in Salinas, Kansas and is in the process of refurbishing the submersible. Just like its sister vehicles, Pisces VI is a three-person research submersible which was designed and built by Hyco International Hydrodynamics of North Vancouver, Canada in 1976, with a maximum operating depth of 2,000 m (6,560 ft). The vehicle



has a 2.1 m hull diameter, made of HY-100 steel with 3 forward-looking 6 inch acrylic viewports. When completed, Pisces VI will be the deepest diving privately owned submersible. The submersible will maintain an operational depth of 2000 m, hold one pilot and 3 observers and is projected to weigh only 15,000 lbs. The design is also focused on streamlining the dimensions in order to fit, along with all support equipment, inside a 20' shipping container. The company's Mission is to provide a low cost deep submersible services for the science and film industry, using Pisces as an underwater platform for exploration and education.

In 2017, the refurbishment of the cabin, the main ballast tank and Frame configuration was completed. Several modifications and additions are planned which include: Battery pack, Ballast air, the variable and main ballast tank arrangement, the thruster arrangement, the interior arrangement and mounting method, the fairings and its transport method to ensure it fits inside a standard ISO container. The company also plans upgrades on the electronics to include Auto Pilot, GPS navigation, a retractable science basket and a lateral thruster system. The company reports operation expected to commence in 2019.

Rainbowfish Ocean Technology Co., Ltd, P.R. China

Rainbowfish Ocean Technology Co., Ltd is based in Shanghai, China. The company's objective is to lead research in deep sea technology, industrialization and marketing within China and internationally. Of special interest is the challenge of hadal zones extremes and creating technology to explore to full ocean depth. Rainbowfish is the commercial partner of the Hadal Science and Technology Research Center (HAST) of Shanghai Ocean University, which was established in 2013. Rainbowfish and HAST announced in 2016 its plans to challenge the 11000m depths with plans to launch a deep research manned submersible rated to full ocean depth.



Supported by Shanghai Ocean University, Professor Cui Weicheng set up the first Hadal Science and Technology research center in China with its goal to develop new frontier deep-sea technology to promote HAST to become a world-famous research and design institution. This cooperation between Rainbowfish and HAST was created to connect scientist and entrepreneurs, utilizing both national support and private investments. At its core is the development of a world-class floating laboratory for hadal science and technology. The project was scheduled in two phases. The first phase focused on the construction of a new 4800 ton research mother ship, "Zhang Jian" and the R&D engineering for the Rainbowfish11000 manned submersible. The second phase plans a series of vehicle tests to full ocean depth (FOD), starting with science landers, followed by a new unmanned Autonomous Remotely operated Vehicle (ARV) and finally leading to the construction and sea trials of the FOD manned submersible. Rainbowfish aims to reach the depth of 11,000 meters in the Mariana Trench which would mark the first time a team of three crew and scientists reach the floor of the Marianna Trench.

In December 2016 to February 2017, Rainbowfish made its first research cruise aboard its research ship Zhang Jian, deploying a set of three FOD landers. All three landers reached the seafloor at the Challenger Deep and performed successfully. The unmanned ARV system was also deployed and reached a maximum depth of 6300 m, hampered by some technical difficulties. The team returned to the lab to improve the ARV design and started the design of the FOD manned submersible vehicle. Through 2017, the major research was focused on the personnel sphere. Rainbowfish engineers elected for a two-part Maraging Steel hemisphere design, like that used on the Russian MIR submersibles. In April 2017 the Finnish foundry TEVO LOKOMO Ltd completed its delivery for the hull after successful pressure testing at the Rainbowfish laboratory in Shanghai. The laboratory has several test chambers, which includes: Three (2) chambers rated to 140 Mpa, one (1) chamber rated to 180 Mpa and an open test tank 10m x 20m x 7m deep.

During 2017, two areas of special focus involved the testing of the acrylic windows and the syntactic foam, due to the desire to have three viewports in the personnel sphere, the size and thickness of the windows was a concern. Based on the ASME PVHO calculations, the window thickness became too thick and a new design smaller configuration was tested based on a smaller included angle from the standard 90 degree conical frustum window. The test results failed to confirm and validate the model. Rainbowfish reported that they start the manufacture of the manned cabin after the successful testing of the window model. Similarly, testing of the syntactic foam material available nationally does not meet the pressure testing to the desired safety factor of 1.5 x maximum operating pressure. The company projects to complete the FOD submersible by 2021.

Rebikoff-Niggeler Foundation, Portugal Azores

LULA1000 is a three person, 1000m rated research submersible operated by the Rebikoff-Niggeler Foundation. The Rebikoff-Niggeler Foundation (FRN) is a Portuguese non-profit organization for marine science located on the island of Faial, Azores. Since 2000, Kirsten and Joachim Jakobsen dive deep around the Azores. In 2017, the team discovered and made multiple dives to document the wreck of the U-581, a German U-boat found at a depth of 870 meters off Pico island. FRN produced a video-documentation of the wreck itself and coral colonies that settled on it, as well as on the habitat



near the wreck. The expedition took still images for a photo mosaic of the wreck using an in-house custom-built camera for photo mosaicking that could integrate the picture in the sub.

Instrumental to the U-boat discovery was the use of Multibeam and sidescan sonar working in great depth when the search started in 2016. U-581 left for the Azores with the order to sink the British vessel Llangibby Castle which, on 2nd February 1942, had to leave Horta harbor on the island of Faial/Azores. The British destroyer HMS Westcott detected U-581 and threw depth charges. The impact of those charges caused severe damage to the U-boat and the commander gave order to the crew to abandon and sink the U-581. U-581 sank in the morning hours on 2nd February 1942, south of Pico island. Four men died at surface from depth charges, 41 men were rescued and became prisoners of war. After analyzing German and British reports about the sinking, the team defined a search area of 4 x 8 nautical miles. A first phase multibeam sonar was used to produce bathymetric 3D charts of the search area. However, because of seamounts in the search area, the sidescan sonar could not be used and the position of the wreck was established with the submersible, producing high resolution video images. As Joachim Jakobsen describes, "The final discovery was made by looking out of the large acrylic viewport of our research submersible. In the end, we were also very lucky. We had been following a deepsea fish for filming on this dive. We followed that fish from 800m to 870m of depth. Suddenly, we noticed a long cigar shaped echo on the onboard sonar of our submersible. We approached and finally had a breathtaking view to the cannon and the tower of U-581."

The wreck represents a valuable object for studies on cold-water corals and the conditions which make possible the creation of coral reefs in great depth. Cold-water corals are considered vulnerable ecosystems. Until now, little is known on the growth rate of such corals. Some species can become several hundreds or even several thousands of years old. Being that the exact date of sinking and thus the maximum age of any colonizing organism is known, valuable conclusions may be drawn from this warship wreck that became a hotspot of deepsea coral life.

During 2017, LULA also dove extensively in research projects for mapping of deep-water habitats off the Azores Islands. The submersible operates in near open ocean conditions and was designed for high quality deep sea filming. In the fifth year of operation, the LULA1000 continued to work on habitat mapping along the islands' often steep slopes. This included documentation of deep-sea fauna and habitats such as sponge fields and coral communities, and collection of base data on the deep-water habitats.

LULA1000 also deployed for deep pelagic dives in the feeding grounds of sperm whales. The dives proved to be extremely challenging and interesting, a research activity that carry on in 2018. The continuous expedition aims to understand what sperm whales find to feed on, and the team reports that the extended bottom time offers the opportunity to film unique and never-seen pelagic species. Part of this incredible footage includes the filming of the whalefall featured on

the Blue Planet II deep episode showing a large number of six-gill sharks feeding on a dead sperm whale.

RIDE – Roatan Institute for Deepsea Exploration Stanley Submarines, Honduras

The Roatan Institute of Deepsea Exploration (RIDE) was established by Stanley Submarines, operating in Roatan, Honduras since 1998. When he was nine, Karl Stanley dreamt about submersibles and launched his first winged, gliding submersible the week he graduated college. The deep submersible “Idabel” was completed in 1998, operating off the island of Roatan where it still takes tourists, film-makers and scientists on dives down to 2000ft.



While the Idabel design was never formally reviewed by a Class Society, the submersible was extensively tested and validated at sea over many years. RIDE is one of three deep diving submersibles in the world offering trips on a continual basis. Through his work diving with the public, research scientists, and personal exploration, Karl Stanley has accumulated a remarkable dive log, piloting over 2000 dives, ranging from 500-2000 feet, and over 5000+ hours at depth.

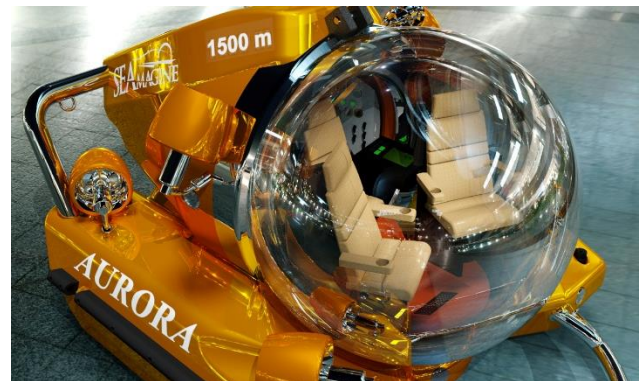
In 2017 and 2018, RIDE continued to fulfill its mission statement by providing the public with cost-effective, direct access to the deep ocean. The company completed the construction of a new watercraft call the sub-sled, designed to dock with Idabel, provide a hydro-dynamic bow and additional ballasts for long-distance towing. This increased the maximum towing speed from 3.5 to 7.5 knots. Since the submersible is launched from shore this innovation drastically increased its range of exploration. On its first mission with the sled, Idabel was towed to an underwater feature 14 miles away. Docking and undocking were safely completed in the open ocean in 4 ft seas. In 2017, RIDE added a custom fish collection device and a temperature & depth recorder to monitor ocean temps on 100+ dives per year. The new animal collection device used an anesthetic solution, when administered to a target fish, dazed or sleeping, the fish is sucked into a collection tank. The system was successfully deployed on 6 dives with researchers from the University of Washington and the Smithsonian, who also funded the project. The research dives collected over 30 fish specimens: 3 entirely new species, 7-10 had only been visually observed in the Caribbean, and the remaining samples were first time collections in the Mesoamerican Reef.

Finally, at the end of the year, Idabel received several system upgrades, most notably an autopilot system.

SEAmagine Hydrospace Corporation, USA

SEAmagine Hydrospace Corporation is a California based company established since 1995 and is a leading designer and manufacturer of small manned submersibles with over 12,000 dives accumulated by its existing fleet. The company produces 2 to 6 Person models with depth ratings ranging from 150 meters to 1500 meters for the professional, scientific, and superyacht markets. All SEAmagine submersibles are classed by the American Bureau of Shipping (ABS) and are based on the company's patented technologies.

The company has been producing its 2 and 3 Person Ocean Pearl models for many years and a new 3 to 6 Person Aurora submarine product line rated up to 1500m. The Aurora design is based on a hyper-hemisphere acrylic cabin with an enhanced field of view by moving the access hatch away from the top of the window into a separate compartment behind the main cabin. This design's ability to tilt at surface provides a stable platform that does not require forward pontoons that restrict peripheral viewing.



During 2017, SEAmagine started the formal submersible pilot and crew training for 10 officers from the Argentinian Coast Guard, called the "Prefectura Naval". The classroom theory classes were given in California and the practical submersible diving exercises were performed in Argentina with the ABS Classed, 350m depth rated, 2 Person Ocean Pearl model that was delivered there in 2016. All practical dive training was performed in the 440m deep fresh water lake called Nahuel Huapi near Bariloche in the Andes of South Patagonia, Argentina. A total of 65 dives were performed during the training down to maximum depth of 300m deep during that training period.

SEAmagine also relocated to its new larger offices and shop facilities in 2017 from Claremont to nearby Upland California. Among other projects, the company is currently under contract for the fabrication of two of its new AURORA submersible models with one vessel depth rated to 460 m and the other to 1000 m. Both new submersibles will be Classed by the American Bureau of

Shipping (ABS) and approved by the Cayman Island Shipping Registry Flag State. The deliveries of these new AURORA submersibles will take place in 2018 and 2019.

Submergence Group, LLC (USA)
MSUBS Ltd. (UK)

Submergence Group and MSUBS Ltd provide manned and unmanned submarines and vehicles for defense, research and commercial sectors. MSUBS is an extension of Marlin Submarines, established in 1986 which built up a portfolio of manned submersibles ranging from tourist submarines to Swimmer Delivery Vehicles and submarine rescue vehicles. In 2016 Lockheed Martin and Submergence Group announced a partnership to build, integrate, test, and deliver three dry combat submersibles (DCS) to US Special Operations Command (USSOCOM). The DCS is designed to support two operators (pilot and navigator) plus up to six swimmers with the ability to lock them out and in.



The DCS contract will supply a new class of seal delivery combat submersibles to operate at greater depths and with longer endurance. In 2017 and 2018, Submergence Group & MSUBS continue to support SOCOM & WARCOC with S351 submersible operations and the construction of the three, new Dry Combatant Submersibles (DCS). The original S301 prototype has been the subject of a CRADA (cooperative Research and development agreement) with SOCOM and continues to be used as an R&D asset for the Navy, now entering its tenth year of operations.

Triton Submarines, LLC, USA

Triton Submarines was formed in 2006 in Vero Beach, Florida and is a leading manufacturer of manned submersibles for science, archaeology, exploration or filming. Triton offers a large selection of models from one and six-person models designed around state-of-the art acrylic pressure hulls and ranging in depth rating from 500 to 1000m and offering a model to 2300m. All Triton submersibles are classed by the American Bureau of Shipping or DNVGL. Triton



submersibles have been used in numerous research and scientific discovery missions around the world, ranging from local Florida surveys to expedition work in the most remote corners of the Pacific. Highlights of these missions include filming the Britannic (sister ship to the Titanic) in the Mediterranean, the first ever manned submersible dives in Antarctica, and the first live footage captured of a giant squid off the coast of Japan.

To date Triton has delivered 11 submersibles including: Two Triton 1000/2, which are 2-person MUVs rated to 1000 ft depth; Eight 3300/3s, which are 3300ft depth rated with 3 person capacity; and one 3300/1 MD (Minimum Displacement) a 3300ft depth rated sub with 1 person capacity.

These submersibles are used both for pleasure, scientific research and to film underwater documentaries. The most active submersible of the family is the Triton 3300/3 Nadir, based on the research ship M/V Alucia which has been used to make many movies/documentaries. In 2017 it was used in the Antarctic to film for the Blue Planet II series. The pair of Triton submersibles based in Malta include a Triton 3300/3 and the Triton 3300/1 and are used for scientific and historical research in the Mediterranean, including filming of the Britannic, the sister ship to the Titanic. Both 1000/2 subs are used for scientific research and documentary filming by the Global Sub Dive group. These were not active in 2017, but just started up again in 2018 with a new host vessel, the Go America.

In the period January to December 2017, Triton completed construction of its eighth Triton 3300/3, and a new model, the Triton 1650/3 LP. This new model is a “Low Profile” design to better fit on superyachts, depth rated to 1650 ft for a 3-person capacity. The company plans to complete a second Triton 1650/3 LP in 2018 and signed a contract for a new 6-man sub, the Triton 3300/6 rated for 3300ft depth rated. In September 2017 at the Monaco Boat Show, Triton announced its Project Neptune, a joint design collaboration with Aston Martin for a 3-person, 500m depth rated submersible. Design work is on-going, and construction is anticipated to start in 2018.

UBoat Worx, Netherlands

U-Boat Worx, was founded in 2005 as a manufacturer of private and luxury submersibles in the Netherlands. The company has a wide range of models ranging from 1 to 9 people and operate to depths up to 1,700m. U-Boat Worx submersible are designed, engineered and built to DNV-GL classification. U-Boat Worx entered in a partnership with Exa Limited, part of the Asian conglomerate Genting Group, in 2013 which enabled the company to increase production and

reduce delivery times. In 2015 U-Boat Worx its first private submersible for a Cruise Ship. This was followed by a C-Explorer delivered for the Crystal Esprit cruise ship and Genting Dream.

The company has developed a range of acrylic submersibles for the private and luxury market, which extends into the tourism market with vehicles of larger capacity. The increasing thicknesses of cast acrylic has enabled large acrylic submersibles to reach ever deeper depths. This is led by specialized capabilities developed by acrylic manufacturers such as EVONIK, in Germany and Blanson Ltd, in the UK.



U-Boat Worx developed a production line approach to build a wide range of models for private explorers, superyacht owners, research vessels and for commercial tourism operation on board of cruise liners. The U-Boat Worx includes the C-Explorer line of 2 and 3-person submersibles rated to 300m depth; the Super Yacht Sub designed as a 3-person model rated to 300 or 500m depth; the HiPer Sub models designed as high-performance vehicles for 2 or 4 person capacity but limited to 100m depth rating.

Uboat Worx has developed two new model series with innovative designs, the C-Researcher for scientific exploration of the deep, and the Cruise-Sub for leisure and tourism. The C-Researcher 2 and 3 offer 2 and 3-person capacity with a maximum depth capability of 3000m for a 2-person model and 2500m for a 3-person model. The Cruise-Sub presents a series of multi-passenger submersibles ranging from capacities of 5 to 11 persons, ranging in depth capacities from 200m (11-person model) to 1700m (for 5-person model).

In 2017, U-Boat Worx delivered two Super Yacht Sub 3 models to undisclosed clients. It also delivered two C-Explorer 5 submersibles for operation on the new World Dream cruise ship, sister ship to the Genting Dream. The company reports having several Cruise Sub models in production with its flagship model the 7-seat Cruise Sub with a depth-rating of 1,140 meters. Construction is on-going and pressure testing of dual acrylic hyper-hemisphere hull with a Titanium mid-section has been successfully completed under DNVGL rules and inspections.

U-Boat Worx reported its sub operations diving at locations around the world, including: Thailand, Malaysia, Philippines, Indonesia, Maldives, Seychelles, Japan, Antarctica, Mediterranean, Caribbean, Scotland, Russia, Greenland and Norway.

US Navy SRDRS and PRM Falcon DSRV, USA

In 2008, the SRDRS (Submarine Rescue Diving and Recompression System) replaced the US Navy's two older DSRVs Mystic and Avalon as the primary deep-sea rescue vehicle for submarine rescue. Unlike Mystic, which could only be transported via modified submarines, the SRDRS was designed as a "fly-away" system that can be mobilized via military or civilian transport aircraft and installed aboard a variety of VOOs (Vessels of Opportunity) upon notification of a submarine in distress. The SRDRS system consists of: 1) The DSRV FALCON, a tethered, remotely-operated Pressurized Rescue Module (PRM), along with its launch and recovery system and 2) the Submarine Decompression System (SDS), that allows rescued submariners to remain under pressure during the transfer from the PRM to hyperbaric treatment chambers aboard the VOO. The TUP (Transfer under Pressure) capability allows sailors to transfer from a pressurized compartment aboard a disabled submarine to a recompression chamber aboard the rescue ship to begin decompression. This is designed to increase the chances of survival and avoid life-threatening consequences of decompression sickness.



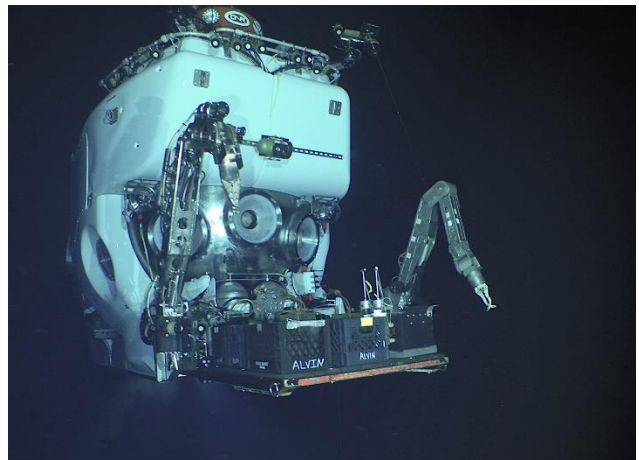
The Falcon is rated to a depth of 2000 ft and designed to mate to a disabled submarine at a list and trim angle of up to 45 degrees. The Falcon has a crew of 2 and can transfer up to 16 personnel at a time. The older DSRVs (MYSTIC & AVALON) operated on batteries are required two-hour battery recharge between dive cycles. The PRM is surface powered via an umbilical and can operate continuously. The SRDRS is operated by the Undersea Rescue Command (URC) homeported in San Diego, a component of Submarine Squadron 11 in Point Loma, California, which is also home to four Los Angeles-class nuclear-powered fast-attack submarines. Phoenix Holdings International is contracted to maintain and operate the SRDRS, provide support maintenance under US Navy certification requirements. These efforts include the support and

maintenance of the SRC rescue chamber and the four 2000ft rated Atmospheric Diving Systems (ADS). These ADS systems were de-commissioned in 2017 and replaced with an ROV system.

While the PRM Flacon has been operational for many years, in 2017 the complete SRDRS system was installed aboard the URC's training ship. This was the first time the Navy fully assembled the TUP capability to connect the PRM to the Decompression chambers. Testing is on-going to support URC's operational training and for the certification of the Navy's deep-sea submarine rescue capability. In November 2017, the Undersea Rescue Command also deployed to Argentina as part of the American response to a missing submarine and its 44 sailors. Three U.S. Air Force C-17 Globemaster III and one U.S. Air Force C-5 Galaxy aircraft transported the the Submarine Rescue Chamber (SRC) and a Remotely Operated Vehicle (ROV). Eight aircrafts were mobilized, the first arriving in Argentina within 43 hours and the last within 120 hours. Two VOOs were mobilized, the first as a search and ROV support vessel, the second as the SRC rescue chamber support ship. The mobilization time to setup each ship was 20 hours for the ROV ship and 68 hours to install the SRC system. Search parties never found the ARA San Juan and the team returned to California in December. The SRC is a McCann rescue chamber designed during World War II and still used today. SRC can rescue up to six persons at a time and reach a bottomed submarine at depths of 850 feet. It is operated by two crewmembers and mate with a disabled submarine by sealing over its hatch allowing sailors to safely transfer to the rescue chamber.

Woods Hole Oceanographic Institution, USA

The Woods Hole Oceanographic Institution's Deep Submergence Operations Group operates the ALVIN submersible. Launched in 1964, ALVIN has seen several overhauls. Since 2012, the latest upgrade was completed which included a new personnel sphere rated to 6500m. Today, the deep submergence vehicle Alvin is America's advanced, state-of-the-art, deep diving submersible available for direct observation and investigation of the deep ocean. Alvin provides a front-seat, first-person diving experience that is



unmatched by remote imaging systems, enabling excellent investigations of deep sea environments. Alvin's numerous sensors provide large quantities of high quality data, and new digital network interfaces allow integration of unique scientific devices and sampling tools. Digital

Images, HD video and dive data travel over a new fiber-optic computer network for superb image collection and advanced systems monitoring and data analysis.

Alvin recently completed the most extensive period of systems upgrades and improvements in its fifty-year history. This included a new, larger personnel sphere with an ergonomically designed interior and enhanced external viewing, digital command and control system, improved propulsion system, advanced imaging system capable of high definition still images and 4K/HD video, new digital scientific instrument interface system, new science workspace and manipulator configuration and numerous other improvements.

Alvin is owned by the U.S. Navy's Office of Naval Research (ONR) and operated as a part of the National Deep Submergence Facility (NDSF) at the Woods Hole Oceanographic Institution. In 2020, Alvin will complete the final systems conversions for operations to 6500 meters, enabling access to over 95% of the world's oceans.

CONCLUSION

The Manned Underwater Vehicles sector is an active international industry that is moving forward at a fast pace and continues to build momentum year by year. Despite a prevalence of unmanned systems in the subsea sector, MUV design and construction is growing and driven by new market trends and new technologies. Commercial growth is specifically in the luxury yachting industry and ocean. The tourism sector is finding new high-end expeditions markets and deep ocean exploration continues to be of national interest in Asia. Developments in materials, batteries and instruments offers an increased array of opportunities for new organizations to develop new underwater vehicles, both for classed designs or experimental concepts. Size and weight remains a focus of attention throughout to find better, more efficient ways to transport MUVs and increase the range of operation. Classification and certification organizations continue to support a well-developed framework of design and construction safety rules, however, little guidance exists for Safety of Operation of MUVs, for which there is on-going industry development to organize best industry practices under a MUV Operations Consensus Standard.

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